A NEW CONCEPT OF METAL REMOVAL WORK UNITS AND THEIR RELATION TO THE CAPABILITIES OF MACHINE-TOOLS

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- PREFACE -

Let us start this thesis with a question: What is meant by Science? What is meant by Scientific Approach? - an expression that we can see in almost every text-book. What do we associate with the idea of application of Scientific Methods?

The author thinks the answer for these questions lies in the definition of the word Science itself. Quoting Webster, "Science can be defined as any department of systematized knowledge, or more extensively, as the accumulated knowledge systematized and formulated with reference to the discovery of general truth on the operation of general laws." The emphasis, therefore, is put upon the word systematized.

The systematization of knowledge, which is obtained through a number of concepts and well-formulated hypotheses, gave to the Gilbreths, Taylor, Gantt, and many others a powerful lever with which to roll the first rocks of the tremendous avalanche of Scientific Management. As a result, Scientific Management left the field of theory, research, and experimentation and joined the field of application, utilization, and every-day-use. Analysis, observation and systematic development based on the important factor of need were the tools which helped the birth of Scientific Management.

Now, with research, they constitute a supporting work for the new Science. It is still not uncommon to find in text-books and technical magazines devoted to Management the "Case Method" being used. Very often, an Executive having a problem to be straightened out, finds that the best thing to do is to rely almost exclusively on experience, thus applying the so-called "Case Method." Solutions are dependent upon how well the problem can be patterned after a specific case. The solution, it can be said, was an after-the-case one. Now, in many cases, the utilization of fundamental concepts permit tailor-made solutions; they can be adapted to each individual problem.

At Purdue University, the so called Production Planning course was completely revised in the summer of 1950, and started almost from the beginning. The concept of "work unit" introduced by O. Musgrave was utilized as a foundation for the new Production Planning Course. However, the teaching staff of GE-183 felt, as usually expected in a new course, that a number of weeknesses existed in the structure of the course. Besides others things, the work units available for metal removal were difficult to organize and group, and due to the excessive number, difficult to manipulate. They weren't flexible enough; and had other faults, such as overlapping with each other.

Therefore, something had to be done to eliminate or at least to minimize those faults.

With that aim in mind, the author of this thesis felt that anything that can contribute to work simplification in a branch of knowledge as far as teaching is concerned, might as well pay dividends in other fields which are closely related to the specific subject to be taught.

All of us know that Industry gets the benefits from the educational programs of Colleges and Universities. The continuation of its life line depends on people with ingenuity, leadership, and knowledge. The ideas, or thoughts which are absorbed by the mass of students will soon come forth in the field of application, somehow, some day.

The work unit approach helped to develop planning concepts and to establish a well-laid framework for processing the work to be done, especially in metalworking. If a more comprehensive and better-balanced system of work units can be given to the metalworking industry, the benefits that this particular industry will receive are numerous. One of these, probably the most important, will be simplification of Production Planning. That's the reason for the thesis title: "A new concept of metal removal work units and their relation to the capabilities of machine-tools."

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- ABSTRACT -

The purpose of this thesis is to introduce a new concept of metal removal work units with the objective of helping the Planner in his work of writing up a Standard Process Sheet. This new approach for the metal removal work units is such that the work units, in a sense, can be disassociated from the machine-tools that perform them.

The procedure adopted in the course of this work, was the following:

1. Literature was reviewed which dealt with the capabilities or performance of metal removal machine-tools. Text-books and technical magazines were also consulted.
2. Manufacturer's views on performance of machine-tools were obtained.
3. Based on the information received, the data collected was categorized in accordance with their use, capacity, tolerances, cutting speeds, feeds, depth of cut permitted, time for setting-up (for simple and for complex operations), rate of output (for representative types of products), and other important information.
4. The above classified data and other important information obtained through a review of text-books and technical magazines, was fitted to the work units proposed. Emphasis was put on the capa-

bilities of the machine-tools and their application to the performance of the different work units.

5. Tables containing important information about machine-tools were organized in an attempt to assist the Planner in his systematic procedure for writing up a Process Sheet.
6. A systematic procedure for the application of the new work units was proposed for the Planner's job.

From the adopted procedure it was found that the proposed group of work units includes practically all the work units in use now-a-days in metal removal.

Finally, the following conclusions were drawn from the procedure used:

1. Work units can be defined in such a way as to avoid their association with the machine-tools that can perform them.
2. By using the proposed group of work units, the sequence in writing up a Process Sheet is a logical one: first the work units are listed; then from the machine-tools that can perform a particular work unit, one is selected in accordance with important factors that might be considered in the Production Planning phase. Finally, from the various tools (assuming that more than one will do), one tool is also selected, after considering such things as the position of the tool in the set-up, its rigidity, the tolerances involved, depth of cut, feed, cutting speed, etc.

3. The possibility of simplifying the Planner's job by furnishing them tables with capabilities of their shop machine-tools has been established.
4. As a by-product of the foregoing, even the possibility of dilution of skill might be foreseen, if one assumes that the "Part Analysis" is done by a Planner with less experience; which means that using the proposed group of work units, that Planner does not have to associate the work units (as it is done now-a-days) with the machine-tool that performs them, leaving the "Method Analysis" to the more experienced one.

A NEW CONCEPT OF METAL REMOVAL WORK UNITS AND THEIR RELATION TO THE CAPABILITIES OF MACHINE-TOOLS.

- INTRODUCTION -

The efficiency of the manufacturing procedures within an industrial organization will largely depend on how well the following questions can be answered: WHAT is going to be manufactured, in WHAT volume and with WHAT cost; HOW and WHEN it will be manufactured, and finally, HOW WELL it is going to be manufactured.

A capable Production Planning & Control Department will be the one which imparts dynamism to a manufacturing concern. With it the Management can be efficient, without it is quite difficult or almost impossible to advance.

A good planning and consequent follow-up procedure will mean the difference between success and failure; to be or not to be in business. In a tight market a few cents or even less will make the difference between getting or not getting a bid, and sound estimating is the foundation which makes that difference. A versatile work process will make the time due deadlines and consequently hold new customers. The proper utilization of the machinery on hand will make an enterprise jump from the red to the black.

Accurate forecasting is the backbone of a profitable industry. Production Planning, which is responsible for the WHAT'S and the HOW is a powerful tool for a conscientious Management. When properly conducted, the Production Planning will permit high efficiency with low expense.

Planning for processing, in its more restricted sense, has the following purposes:

1. Part Analysis of the material, that is: listing the work units to be performed in the specific part piece.
2. Method Analysis, that is: group the work units listed into operations, and combine the latter in such a sequence as to obtain the most efficient and economic way to manufacture the part piece with the equipment that is available.
3. Determination of economic lot sizes in repetitive manufacture.
4. Making the cost estimate of the part piece.

In this thesis the author will be concerned with part of the first item presented above. To be more specific: listing and defining work units which deal with Metal-Removing methods in order to help Planners.

When one faces the problem of planning for processing in metalworking with the procedures now in use, he will depend almost exclusively on work units which are intimately associated with this or that machine-tool.

When the removal of metal is to be done on a part piece, the immediate concern of the Planner is to get the machine-tool which can perform that particular work unit. Then, and only then he picks up the name of the work unit that is going to be performed. We can assume that a trained Planner will do that thinking without being aware that he first

picks the machine-tool and then the work unit.

Suppose that one has to make a surface flat. If the machine-tool chosen for the job is a shaper, the work unit will be named: SHAPE; but the Planner might decide to do the job in a surface grinder, so, why not change the name of the work unit to SURFACE GRIND? or he might choose a milling-machine, and then the work unit will be named PLANE MILL; finally, why not choose a broaching machine - by the same token the work unit now will be BROACH.

So, we can ask ourselves: Why not divorce the name from the machine-tool or even the tool when we think in work units? Why not subordinate the machine-tools or the tool to the work unit to be performed in the part piece, instead of the reverse.

As with many others things in engineering, the shop language became the engineering language. Probably it was through the shop that the work units in use now-a-days became popular and were picked by the Production Planners in their more organized approach towards efficient processing. This leads us to believe that no concept was involved, no necessary precautions were taken, no systematized approach was made towards developing a consistent work unit terminology.

The idea of the author of this thesis is to try to establish a group of metal removal work units based on some concept more flexible than the one based on machine-tools or tools that might perform them. That is, a basic group

of work units which can easily be associated with the part piece, and not to the machine-tool which might perform that particular work unit.

- APPROACH -

The idea of associating the work units with the machine-tool that is going to perform it, or even with the tool that is going to be used in the cutting process is almost universal. This idea is so deeply rooted that it can be given the name of tradition. Due to that fact, the author of this thesis feels that the job ahead is not an easy one.

The author's first thought was to analyse the procedures used in general by the Planners and to see how all the steps in writing up a Process Sheet could be integrated. Soon it was felt that the Planner should first list all the work units to be performed in the part piece, without thinking about the machine-tool or machine-tools that could perform those work units. Once all the work units were listed, the Planner could then choose the machine-tools that could perform the work unit by analyzing the machine-tools in the light of the tolerances, rate of production, surface finish characteristics, and other factors involved. In that step was found the weak point of the procedure. That is, very often the work unit used as basis for the machine-tool analysis did not represent a unit as it should be. By that the author means that the work unit should be common to the machine-tools that can perform it, which is not true in many cases. This has already been pointed out in the introduction.

It was felt that the key point in making the approach for the new work unit concept, should be such that the step from the "Part Analysis" to the "Method Analysis" has to be done as smoothly as possible, without going back and forth as sometimes is done.

The author feels that associating the geometry of the part piece with the work units to be performed on it would help in divorcing the work units from the machine-too. By using that approach, the problem of going from the "Part Analysis" to the "Method Analysis" might be solved.

When one reads a blue print, what he does actually is to mentally project into space the part drawn. Instinctively, he associates the contour of the part piece with some geometric surface.

From the geometry of the surfaces one knows that they can be classified as surfaces of rotation and non-rotational surfaces, the latter being composed of plane surfaces and/or curved surfaces.

A surface of rotation or revolution is one generated by the rotation of a line about an axis.

When a surface is generated such that a straight line joining any two of its points lies wholly in the surface, or more precisely: a surface when turned over is congruent with itself, one calls that type of surface a plane.

Finally one can have generation of curved surfaces, which generation can be classified as non-rotational surfaces.

The author, based on what was said above, proposes the following classification of surfaces to be associated with the metal removal work units.

1. Surfaces of rotation.
2. Plane surfaces.
3. Symmetrical combination of plane and/or curve surfaces.
4. Others.

THE WORK UNITS PROPOSED

To the generation of surfaces of rotation, the following work units are going to be associated:

External ROUND and Internal ROUND.

These work units are associated with the generation of any type of surface of rotation, such as: cylindrical, conical, spherical, parabolic, hyperbolic and elliptic, or combination of one or more of these surfaces, which generation is done externally or internally with respect to the part piece.

Due to the fact that the surfaces of rotation appearing most in metal part pieces are either cylindrical, conical, or a combination of both, the author is going to further break down each of the work units External ROUND and Internal ROUND into the following work units:

11. Straight ROUND - the work unit associated with the generation of a cylindrical surface of rotation.

12. Taper ROUND - the work unit associated with the generation of a conical surface of rotation.

To the generation of plane surfaces the following work units are going to be associated:

21. External FLAT - the work unit associated with the generation of a plane surface, externally with respect to the

part piece.

22. Internal FLAT - the work unit associated with the generation of a plane surface, internally with respect to the part piece.

To the generation of symmetrical combinations of plane and/or curved surfaces the following work units are going to be associated:

External CONTOUR and Internal CONTOUR. These work units are going to be further broken down into the following work units:

31. Straight CONTOUR-the work unit associated with the generation of a symmetrical combination of plane surfaces.

32. Curve CONTOUR - the work unit associated with the generation of a symmetrical combination of curved surfaces.

33. Compound CONTOUR-the work unit associated with the generation of a symmetrical combination of plane and curved surfaces.

To the generation of surfaces which do not fall into the foregoing categories, the following work units are going to be associated:

41. Helical CONTOUR -the work unit associated with the generation of a ridge of uniform section in the form of a helix

on the surface of a cylinder.

42. Spiral CONTOUR - the work unit associated with the generation of a ridge of uniform section in the form of a conical spiral on the surface of a cone or a frustrum of a cone.

43. Irregular CONTOUR - the work unit associated with the generation of a surface which has no special geometry.

In order to make more clear the applicability of the proposed group of work units, the author presents the relationship between those work units and the ones that are actually in use.

Straight ROUND -

Straight turn	Ream
Drill	Trepanning
Bore	Hole broaching
C'bore	Internal grind

Taper ROUND -

Chamfer
C'sink
Taper bore
Taper ream
Taper turn

FLAT -

Plane mill	Surface grind
Face mill	Surface broach

Face
Hollow mill
Slab mill
Bevel
Shape

Straight CONTOUR-

Slot
Gang mill
Straddle mill
Key way
Broach

Curve CONTOUR -

Form mill
Broach
Form shape

Compound CONTOUR-

Key seat (milling cutter)
Straight spline
Straight flute

Helical CONTOUR-

Threading
Helical flute
Tap

Spiral CONTOUR -

Threading
Spiral flute

Irregular CONTOUR -

Form
Profile

Finally, work units in use like neck, groove, form turn, form face and profile turn, can be associated with the ones proposed, when one thinks that all the former can be related to combinations of surfaces of rotation (cylindrical or conical) and/or plane surfaces. Therefore, one can say that:

Neck - combination of straight ROUND with FLAT.

Groove - combination of straight ROUND with FLAT.

Form turn - combination of ROUND.

Profile turn - combination of ROUND.

Form face - combination of straight ROUND with FLAT.

The author of this thesis feels that the proposed group of work units embraces all work units in use as far as metal removal work units are concerned. However, for the sake of easier application, a finer breakdown is going to be made and a new group of work units is going to be introduced.

The finer breakdown will be made on Internal straight ROUND and the new work units to be included are related to:

(a) Separation or partition of metal.

(b) Surface finish by metal removal.

The finer breakdown on Internal straight ROUND will be related to methods of producing and enlarging holes.

51. OPENHOLE - the work unit associated to the producing of a hole where none had been previously.

52. HOLENLARGE - the work unit associated to the

enlarging of a hole.

The author feels that these work units are so characteristic that they might as well form a separate group. The work unit OPENHOLE will embrace the work units "drill" and "trepanning" in use now-a-days.

The work unit HOLENLARGE will embrace all the work units in use now-a-days for the purpose of enlarging holes, such as "bore", "hole broaching", "internal grinding", etc.

To the separation or partition of metal the following work unit is going to be associated:

61. PART - the work unit associated with the separation of the stock from the parent metal.

Sticking to the premise that the Planner shouldn't think about the machine-tool when performing the "Part Analysis", the work unit PART is presented. This means that when a part piece has to be separated from the stock, the Planner will just list the w. u. PART and then he will be free to determine which machine-tool should do that work unit and also with what kind of tool the particular work unit should be performed. Under this heading the work units in use now-a-days, such as: "saw" and "cut-off", would fall.

Finally comes the surface finish group of work units. The author is aware of the fact that many of the foregoing work units, when performed with special attachments (piloted bars in lathes; servo-mechanism: hydraulic, mechanical,

electric, electronic or combination of them) or special tools (diamond-tipped tools) and high sfpm, make possible very good surface quality. Nevertheless, the author feels that abrading methods such as grinding, lapping, honing and superfinishing are so characteristic that they are entitled to be covered by a work unit. It is true that in the light of the procedure adopted so far: association of the work units to the geometry of the part piece, that even the abrading methods should come within the geometrical concept. One thing that can be done is to say: FINISH Internal ROUND (which embraces: diamond boring, internal grinding, lapping, honing and superfinish) and everything would be settled. However, the author feels that a name should be given to a work unit which deals with surface quality of the part piece. This is the reason for the introduction of:

Work units related to the surface finish of the part piece, provided they are associated with metal removal methods:

External SURFACEFINISH and Internal SURFACEFINISH.

A PROCEDURE FOR THE APPLICATION OF THE NEW WORK UNITS

1. The Planner gets hold of the Blue Print, identifies the surfaces to be machined, the surfaces to be finished, the holes to be opened, the ones to be enlarged, the tolerances involved and finally information about the stock from which the part piece will be made.
2. Once he has the geometrical concept of the part piece, he starts to analyse the part, surface by surface, and at the same time he identifies them with the work units proposed. If a plane surface is needed, the association is with FLAT; if a surface of rotation is at sight, the association is with ROUND; if the need is for non-rotational surfaces, then the association is with CONTOUR. If holes should be opened and/or enlarged the work units to be chosen are OPENHOLE and/or HOLENLARGE.
3. After the first step in this approach is made the Planner starts to make a finer breakdown in the work units selected. He will decide if the ROUND is straight or tapered, if the CONTOUR is straight, curve, compound, etc., or if these work units are external or internal with reference to the part piece.
4. The third step will be to list the work units proposed in order to machine that part piece, taking care to associate (with some identification means) the work units listed to the surfaces they are related with.

5. Then the Planner will get hold of the charts and tabulations (similar to the ones the author has presented, though in this case they would be based specifically on the machines he has at his plant) and pick the different machines that can perform each work unit.
6. Finally, based on the capabilities of each machine-tool and on the tolerances and surface finish characteristics of the surface in question, a machine-tool is selected to perform the specific work unit chosen.

- CONCLUSIONS -

Looking back at the initial assumption: the relation of the work units to the geometry of the part piece, the author of this thesis thinks that it pays dividends. During the work in gathering material for this thesis, (that is, consulting the technical books, pamphlets from the different machine-tool manufacturers, periodicals, technical magazines related to the subject, and talking to professors from the GE staff and other professional people), the author developed the belief that we must have headings or pockets into which any metal removal work unit can be placed without the trouble of associating them with machine-tools. If one had the time to list all the work units that might be performed by the different machine-tools, with respective attachments, this listing would take a large number of printed sheets of paper. In addition, the author calls attention to the fact that in almost every shop, one will find different names associated to the same work unit, or perhaps, a finer breakdown for well established work units. As an example of what was said above, the author knows of a plant in Warren, Pennsylvania, where a semi-finish bore when done in the bore of a gun tube is called "hognose"; and also where a finish turn done in a rough casting for the purpose of helping to mark the center of the part piece, is called "spot". Another small plant specializing in

knurling has this work unit sub-divided into a finer breakdown according to the different types of cutters used to impart different patterns in the part piece.

Three main conclusions can be drawn from the thesis presented:

1. Work units can be defined in such a way as to avoid the association with the machine-tools that can perform them.
2. In writing up a Process Sheet, one should first determine the work units, then the machine-tool to perform the particular work unit chosen, and then should indicate the tool with which the work unit can be accomplished. In other words, this means that the sequence in writing a Process Sheet can be a logical one. First the work units are listed; then from the machines that can perform a particular work unit, one is selected, in accordance with the other factors that might be considered in the production planning phase. Finally, from the various tools (assuming that more than one will do) one is also selected, after careful consideration of the position of the tool in the set-up, its rigidity, the tolerances involved, depth of cut, feed, cutting speed, etc. One should never forget the fact that in many cases, the names to be associated with this or that particular work unit might be dependent on the needs and on the policy used by the Manage-

ment with respect to Planning procedures.

3. The final conclusion is the fact that if each Planner from a Production Planning division is furnished with, or has immediately access to, tables or charts similar to the ones presented in this thesis, his work would be probably simplified. In addition, the planning could be done with less dependence on the memorization factor, with more uniformity, and probably the most important of all; with less training than would otherwise be necessary. As a by-product of the foregoing we can also assume that the Planner's work can be in a sense diluted, that is, once the work unit is associated with the geometry of the part piece, the so called "Part Analysis" might be done by Planners with less experience, leaving the "Method Analysis" to the ones with more experience or training.

Another thing to be thought upon, though the author doesn't feel it should be considered as a conclusion of the work done, is the fact that if one accepts the proposed group of work units embracing almost all the work units in use nowa-days, the former can at least be used as headings for the purpose of classification or organization, with the obvious possibility of helping the presentation in teaching.

APPENDIX A

- TABULATIONS -

In order to organize the tabulations, the following steps were taken:

1. Based on the information received from several machine-tool Manufacturers (1) an attempt to categorize all the data collected was made, using the following factors:

   11. Use of the machine-tool.

   12. Design:

      121. Capacity of the machine-tool for handling work.

      122. Information about handling, locating, fastening, etc., for production.

      123. Tolerances and quality of surface machined.

      124. Speeds, feeds and depth of cut.

   13. Cost:

      131. Set-up time for simple and for complex operations.

      132. Lot size or production quantity for representatives types of products which are economically machined by the specific machine-tool.

      133. Cost of the machine-tool.

      134. Rate of out-put for representatives types of products.

(1) - Bibliography

14. Materials which are best machined with the specific machine-tool.

15. Miscelaneous:

    151. Relative classification of the machine-tools as far as safety is concerned.

2. The above classified information or data plus other information obtained from text-books, technical magazines, etc., was fitted to the proposed work units (based on the geometrical approach). Emphasis was put upon the limitations or capabilities of the machine-tools as applied to the performance of the different work units.

The author feels that, in order to avoid repetition, the items: 11, 121, 122, 131, 132, 133, 134, 14 and 151 which are more intimately associated with the machine-tools, are going to be presented once in the following tabulation. However, the items: 123 and 124 will be broken down and associated to each of the proposed work units:

The tabulation is going to be presented in two parts:

a) Tabulation I related to items 11, 121, 122, 131, 132, 133, 134, 14 and 151.

b) Tabulation II related to items 123 and 124.

Note: The item 133 was dropped because very little information on cost of machine-tool was obtained.

- TABULATION I -

The following machine-tools were analysed:

1. Lathes - engine, turret, automatic and automatic screw machine.
2. Milling machine - emphasis was put upon production milling machines.
3. Drill Press - upright, gang and radial.
4. Boring machine - horizontal spindle, single or double end automatics.
5. Shaper and Slotter.
6. Planer.
7. Broaching machine.
8. Grinding machine - cylindrical, centerless and surface.

The following items were used:

1. Use of the machine-tool.
2. Capacity.
3. Handling, locating, fastening, etc., for production.
4. Set-up time for simple and for complex operations.
5. Lot size or production quantity for representative types of products.
6. Rate of out-put of representatives types of products.
7. Material
8. Safety.

FEATURES / MACHINES	USE	CAPACITY	HANDLING, LOCATING, FASTENING, ETC.	SET-UP TIME	LOT SIZE	RATE OF OUTPUT	MATERIAL	SAFETY
ENGINE LATHE	A machine designed primarily to produce surfaces of rotation. Extremely large pieces can be efficiently machined on engine lathes.	Maximum - swing over bed: 60½" distance between centers: 312" Minimum - swing over bed: 4"		For large work such as guns, crank-shafts, etc., can go as high as 1½ to 2 hours.			High machinability steels are preferred for production jobs. Hard, semi-steel or medium carbon steel castings may require reduction in cutting speeds, to as low as 40 sfpm with accompanying lower output and higher tool cost. Commercial brass, Al and bronze can be finished at high speeds.	Rel. Class.: 4th trailing grinding machines, automatic screw machines and drill presses.
TURRET LATHE	Also a machine designed to produce surfaces of rotation. Although adapted to produce parts in quantity too limited to be economically produced in an Automatic Screw Machine, the Turret Lathe is primarily suited for parts not within the capacity of the A.S.M. Uses multiple and combined cutting.	Ram type - maximum: round stock: 2¼" length: 24" swing over bed: 20" chucking work: 15" minimum: round stock: 3/8" length: 4" Saddle - maximum: round stock: 12" length: 93" swing over bed: 36½" chucking work: 32"	Try to make part piece symmetrical for chucking facilities. Design for ease and speed in gripping work. Design for a minimum of surface to be finished in turret lathe. The so-called chucking extensions are often required in order to provide a practical method of holding.	Can vary between ½ hour to 3½ hours.	Justified to use for 15 to 100 pieces.		Same considerations used for Engine Lathes can be applied here.	Rel. Class. same as Engine Lathe.
AUTOMATIC LATHE	As any other lathe, the Automatic Lathe is designed to produce surfaces of rotation. Employing primarily single point tools, it is ideally suited for the production of wide variety of machine parts. Unlike Turret Lathes and A.S.M., these lathes are well adapted to the machining of forgings, castings, and bars held between centers, or work supported on fixtures, as well as ordinary chuck work.	Maximum - diameter: 32" length: 99" Minimum - diameter: ½" length: 2½"	Try to reduce to minimum handling time due to the speed of turning. The possibility of hopper or chute feed should be considered. Design for easy chucking or holding. Because the operator often handles several machines, chucking time is at a premium. Don't design so as to use complicated form tools. They are not used in Automatic Lathes. Avoid undercuts and provide parts for cutting reliefs.	Is short. In many cases design changes and improvements on parts being run involve little or no cost over set-up.	May justify use for above 100 pieces.	As a rule, floor to floor time averages around 30 sec. ranging from a minimum of about 7 sec. (3 sec. machining time) to around 5 min.	Same consideration applied for Engine Lathes can be used here.	Rel. Class. same as Engine Lathe.
AUTOMATIC SCREW MACHINE	Designed to produce surfaces of rotation in rapid succession, using either single point tool or form tools, which surfaces can be either of simple or intricate design.	Single spindle - Maximum - solid bar stock diam.: 8" tubing diam.: 9½" length: 9" Minimum - solid bar stock diam.: 5/16" length: 3/4" Multiple spindle - Maximum - stock diam.: 7" length: 9" Minimum - stock diam.: 9/16" length: 5" Chucking - Maximum - swing: 12" length: 8" Minimum - swing: 6" length: 6"	Simplest shapes are reproduced more easily with minimum of tooling. One of the most efficient methods of production when shapes are simple is by the use of form and cut-off tools. However, to obtain the benefits of such method the ratio of length of form-tool to the smallest diam. to be machines should not exceed 2.5:1 if the work is unsupported. Perfectly square shoulders can be produced on parts finished from one end with hollow mills, balance turning tools or box tools. Filleted corners and chamfered edges are preferred to sharp ones inasmuch as tool life is greatly improved. Holes, wherever possible, should be shown as opened with a standard drill point at the bottom. Holes up to 3 or 4 times their diam. in depth can be produced in one pass. For maximum economy A.N.S. threads always should be specified, the fine series of this standard being most satisfactory. Blind holes require plenty of chip clearance (5 threads in length - minimum).	For single spindle bar- usually not more than 2½ hours. For single spindle chucking - 3 hrs. is an overall avg. time. For multiple spindle - from 4 to 8 hrs., the 4½ hours is an overall avg. time.	Minimum number of part pieces - 1,000. High production running to 100,000 or more would usually justify the use of A.S.M.	As high as 4,000 pcs. per hr. Using Turret Lathe production time as one, a 5 spindle automatic will outproduce it five times and the single spindle will out-produce it 2 times.	Naturally, materials which can afford easy machining at max. speeds provide the lowest cost parts and the least expensive tooling. Free machining brass is perhaps the most widely used material for general purpose parts. Free machining cold rolled steel or cold drawn Bessemer screw stock, B1113, (AISI), should be specified wherever and whenever design in steel permits.	Rel. Class.: 2nd trailing grinding machines.

AUTOMATIC SCREW MACHINE	Designed to produce surfaces of rotation in rapid succession, using either single point tool or form tools, which surfaces can be either of simple or intricate design.	Single spindle - Maximum - solid bar stock diam.: 8" tubing diam.: $9\frac{1}{2}$" length: 9" Minimum - solid bar stock diam.: 5/16" length: 3/4" Multiple spindle - Maximum - stock diam.: 7" length: 9" Minimum - stock diam.: 9/16" length: 5" Chucking - Maximum - swing: 12" length: 8" Minimum - swing: 6" length: 6"	Simplest shapes are reproduced more easily with minimum of tooling. One of the most efficient methods of production when shapes are simple is by the use of form and cut-off tools. However, to obtain the benefits of such method the ratio of length of form-tool to the smallest diam. to be machines should not exceed 2.5:1 if the work is unsupported. Perfectly square shoulders can be produced on parts finished from one end with hollow mills, balance turning tools or box tools. Filleted corners and chamfered edges are preferred to sharp ones inasmuch as tool life is greatly improved. Holes, wherever possible, should be shown as opened with a standard drill point at the bottom. Holes up to 3 or 4 times their diam. in depth can be produced in one pass. For maximum economy A.N.S. threads always should be specified, the fine series of this standard being most satisfactory. Blind holes require plenty of chip clearance (5 threads in length - minimum).	For single spindle bar- usually not more than $2\frac{1}{2}$ hours. For single spindle chucking - 3 hrs. is an overall avg. time. For multiple spindle - from 4 to 8 hrs., tho $4\frac{1}{2}$ hours is an overall avg. time.	Minimum number of part pieces - 1,000. High production running to 100,000 or more would usually justify the use of A.S.M.	As high as 4,000 pcs. per hr. Using Turret Lathe production time as one, a 5 spindle automatic will out-produce it five times and the single spindle will out-produce it 2 times.	Naturally, materials which can afford easy machining at max. speeds provide the lowest cost parts and the least expensive tooling. Free machining brass is perhaps the most widely used material for general purpose parts. Free machining cold rolled steel or cold drawn Bessemer screw stock, B1113, (AISI), should be specified wherever and whenever design in steel permits.	Rel. Class.: 2nd trailing grinding machines.
MILLING MACHINE	Well suited and readily adapted to the economical production of any quantity from a few parts to a multitude, with an almost unlimited versatility of part pieces whose surfaces after machined are not surfaces of rotation.	Plain & Universal - Table working surface: maximum: 143" by 28" minimum: 49" by $9\frac{1}{2}$" Automatic - Table working surface: maximum: 108 5/8" by 26" minimum: 13 3/8" by 5 1/4"	Whenever possible the part design should be such, that a maximum number of surfaces can be milled at one pass. Slots of greater depth than three times the cutter width should be avoided. Allowance should be made for standard cutter corner radii. Angle between milled faces should be 90 degrees wherever possible. Where external edges are to be rounded, standard concave cutter radii should be specified. Avoidance of cuts requiring small diameter cutters is advantageous, especially with high speed milling.		Readily adapted to the economical production of any quantity, from a few parts to a multitude.		The advent of high speed milling brought into the practical production range most of the low-machinability metals, such as the lightweight alloys. Work-hardened steels can also be economically machined at 900 sfpm.	
DRILL PRESS	Primarily for opening holes.	It can open holes from 0.002" to 4" in diam. Upright - Drill to center of circle or table: up to 29". Distance spindle to table: from 3/4" to 33 3/4". Gang - Standard distance between spindles: from 20" to $29\frac{1}{4}$". Distance spindle to table: a maximum of 32". Radial - Length of arm: from 3 to 12 ft. Diam. of column: from 9" to 26".	Drilling machines should be used to open holes wherever possible, especially with holes 1" or under. Opening holes with ordinary drills allows production of hole depths up to about 5 times the drill diam. Holes should be opened all the way through. Where ready positive location is not possible, lugs should be provided for that purpose.				The ones which afford easy machining at high speeds, such as resulfurized carbon steels, especially B1112 and B1113 (AISI). Many non-ferrous bearing metals, aluminum, etc., do not finish to desired surface quality, but spell and pick up.	Rel. Class.: 3rd trailing grinding machine and A.S.M.
BORING MACHINE	While reaming is widely used to size holes more accurately than is possible with drills, the Boring Machine is, as a rule, used to size holes in order to obtain the maximum in precision sizing and location.	Minimum diam. of hole to be enlarged: $\frac{1}{4}$" Horizontal Spindle - used for large and bulky work. Table size: from 4" by 48" to 48" x 134" Vertical capacity: up to 36" Enlarge holes: from 8" to 20" or even more Single or double end automatic machines - used for smaller parts. Distance from top of table to top of bridge - 4" to [illegible] Distance between bridges (double end) - $25\frac{1}{2}$" to 72". Maximum table travel: from 8" to 25".	Practical limit of hole length to diam. to be enlarged is about 4:1 (with unpiloted or unguided bar). Solid cemented carbide boring bars permit precision boring of holes up to 8 times the diam. of hole in length or depth. If at all possible small blind holes should be avoided. The problem of locating and holding a part in a fixture should always be kept in mind.		Large Universal Boring machines are limited to small lot production. The smaller ones and even Jig Borers can be employed for medium or even larger quantity of work, especially the multiple heads.	As high as 250 pcs. per hr. can have diam. enlarged in multiple-head boring machines.	Same consideration given to Drill Press can be applied here. We can add that extremely hard material such as Ni Hard, ordinarily considered unmachinable, can be readily cut by boring machines to sufficient accuracy, for production purposes, by using sintered carbide tools.	

MACHINES	USE	CAPACITY	HANDLING, LOCATING, FASTENING, ETC	SET-UP TIME	LOT SIZE	RATE OF OUTPUT	MATERIAL	SAFETY
SHAPER & SLOTTER	Primarily intended for rough metal removal and finish to precision flat surfaces on parts which can be readily handled with a fairly short stroke.	Stroke length for Shapers - from ½" to 38". Stroke length for Slotters can be as high as 48".	Locating pads, clamping brackets, bracing, stopping, measuring or clamping pieces, etc., may be added to the part piece with considerable cost justification.		Although in a great many cases confined to the production of one or several identical pieces, a tremendous number of high production machine parts are also produced by each of those machine-tools.	Key ways can often be cut in an avg. time of 30 seconds.	Practically any material can be used, though cast iron (soft, medium or high), steel (free cutting, average and low-machinability), bronze and Al are more easily and economically machined.	Rel. Class.: less safe than Grinding Mach., A.S.M., Drill Presses and Lathes.
PLANER	Suited primarily for producing flat surfaces on parts both too long and too cumbersome for the Shaper.	Stroke length - from 8" to 99". Width between housing - up to 144". Maximum height under rail - up to 120".	Locating pads, clamping brackets, bracing, stopping, measuring or clamping pieces, etc., may be added to the part piece with considerable cost justification. Inasmuch as table reversals on a Planer are often not as precise or as instantaneous as on a Shaper, adequate room for reversal of the tool should be comtemplated. Where slides, pads or attachment surfaces are adjacent to an edge, wall or other interference a relieved portion between should be allowed where no finish is necessary. This relief can be several inches or greater if possible in width and sufficient depth to clear all finished edges. To insure use of maximum possible finishing speeds, the parts should be designed for rigidity. As many surfaces as possible should be designed so as to fall in the same plane.				Same consideration as Shaper and Slotter.	Rel. Class.: Same as Shaper and Slotter.
BROACHING MACHINE	A machined designed for extremely high-speed production of parts with different shapes, which makes possible low cost per piece of extremely complex parts and highly repetitive accuracy.	Vertical Broaching Mach., strokes: from 4" to 84". Horizontal Broaching Mach., strokes up to 120". Continous Broaching Mach., can broach in one pass up to 90".	Thin wall sections do increase difficulties for the use of Broaching Mach. Parts that are quite short in the direction of broach travel, sometimes present distinct problem. Extremely long parts also offer difficulties (especially on internal work units, due to chip disposal). Especially when more than one pass is used, care should be taken to hold concentricity.		Can be applied to considerable advantage for production quantities of 2,500 to 5,000 pieces.	Up to 1,400 pieces per hr. (round holes). As high as 1,000 pieces (flat surfaces, with automatic loading).	Almost any material that can be machined by other machine-tools, can be also machined by a Broaching Mach. For best results, tough material with hardness held between Rockwell C25 and C35 should be used. Harder material can be used, but sometimes involve problems of wear and lubrication. Softer ones are often too "mushy" or tend to tear, burr or adhere to the acting teeth and overload the tool, impairing surface finish. Stock variation can also represent quite a serious problem.	
CYLINDRICAL GRINDER	A machine designed primarily for finishing surfaces of rotation by removing extremely minute chips from those surfaces, by means of abrasive wheels.	Plain and Roll - Length between centers: from 12" to 288". Swing: from 4 15/16" to 62". Universal - Length between centers: from 20" to 72". Swing: from 10" to 19". Oscillating - Work up to 9" OD and 3/8" to 8" ID by 6" in length can be handled. Internal or Chuck - Takes diam. from 0.040" to 50".	Simplicity of design. Try to eliminate interrupted surfaces immediately adjacent to full continuous cylindrical surfaces which serve as bearings. Make parts to be ground easily accessible. Provide parts with grinding reliefs. As a rule, for internal Grinders holes under 0.040" should be avoided. Where external work units can be substituted for internal ones, production will be simplified. Wherever center grinding is indicated, part design should contemplate the use of center holes, which can be retained throughout the processing of the part piece.	For simple grinding it may range from 5 to 15 min. and on semi-automatic machines where automatic sizing is included perhaps an additional 5 or 10 min.		As high as 500 pieces per hr.	The scope of grinding embraces all of the ferrous metals including those which are hardened. All the non-ferrous metals such as copper, brass, aluminum, magnesium, bronze, etc., can be readily ground.	Rel. Class.: The most safe.

BROACHING MACHINE	A machined designed for extremely high-speed production of parts with different shapes, which makes possible low cost per piece of extremely complex parts and highly repetitive accuracy.	Vertical Broaching Mach., strokes: from 4" to 84". Horizontal Broaching Mach., strokes up to 120". Continous Broaching Mach., can broach in one pass up to 90".	Thin wall sections do increase difficulties for the use of Broaching Mach. Parts that are quite short in the direction of broach travel, sometimes present distinct problem. Extremely long parts also offer difficulties (especially on internal work units, due to chip disposal). Especially when more than one pass is used, care should be taken to hold concentricity.		Can be applied to considerable advantage for production quantities of 2,500 to 5,000 pieces.	Up to 1,400 pieces per hr. (round holes). As high as 1,000 pieces (flat surfaces, with automatic loading).	Almost any material that can be machined by other machine-tools, can be also machined by a Broaching Mach. For best results, tough material with hardness held between Rockwell C25 and C35 should be used. Harder material can be used, but sometimes involve problems of wear and lubrication. Softer ones are often too "mushy" or tend to tear, burr or adhere to the acting teeth and overload the tool, impairing surface finish. Stock variation can also represent quite a serious problem.	
CYLINDRICAL GRINDER	A machine designed primarily for finishing surfaces of rotation by removing extremely minute chips from those surfaces, by means of abrasive wheels.	Plain and Roll - Length between centers: from 12" to 288". Swing: from 4 15/16" to 62". Universal - Length between centers: from 20" to 72". Swing: from 10" to 19". Oscillating - Work up to 9" OD and 3/8" to 8" ID by 6" in length can be handled. Internal or Chuck - Takes diam. from 0.040" to 50".	Simplicity of design. Try to eliminate interrupted surfaces immediately adjacent to full continuous cylindrical surfaces which serve as bearings. Make parts to be ground easily accessible. Provide parts with grinding reliefs. As a rule, for internal Grinders holes under 0.040" should be avoided. Where external work units can be substituted for internal ones, production will be simplified. Wherever center grinding is indicated, part design should contemplate the use of center holes, which can be retained throughout the processing of the part piece.	For simple grinding it may range from 5 to 15 min. and on semi-automatic machines where automatic sizing is included perhaps an additional 5 or 10 min.		As high as 500 pieces per hr.	The scope of grinding embraces all of the ferrous metals including those which are hardened. All the non-ferrous metals such as copper, brass, aluminum, magnesium, bronze, etc., can be readily ground.	Rel. Class.: The most safe.
SURFACE GRINDER	A machine designed primarily for finishing flat surfaces, by removing extremely minute chips from those surfaces, by means of abrasive wheels.	Horizontal - Takes work up to 30" x 48" x 196", with tables up to 240" in length. Vertical - Diam. up to 96". Disc - Length up to 14".	As far as production is concerned, surface areas to be finished should be kept to a minimum. Surfaces should be relieved to offer only the necessary area required for matching or fitting. To adapt a design for surface grinding, no projections or steps in the surface level should be present. Care should be exercised with hardened parts so as not to remove the hardened case in grinding to finish dimensions.			As high as 470 pieces per hr.	Same considerations as with Cylindrical Grinders.	Rel. Class.: Same relative classification as Cylindrical Grinders.
CENTERLESS GRINDER	A machine designed primarily for finishing surfaces of rotation by removing extremely minute chips from those surfaces as on the Cylindrical Grinder, but at a much higher rate of production.	Straight - Short work (work rest): from 1/16" to 10" diam. Bar work: from 1/8" to 4" diam. Length: up to 18 ft. In feed - Diam. up to 7" and length up to 36". Internal - Maximum depth of hole: 36". ID from $\frac{1}{2}$" up, in parts with OD $4\frac{1}{2}$", in smallest machines, and 3" up with OD to 9" in the largest.	Same considerations as on Cylindrical Grinders.			With Plunge or In-feed, production can be as high as 1,000 pieces per hr.	Same considerations as on Cylindrical Grinders.	Rel. Class.: Same relative classification as Cylindrical Grinders.

APPENDIX B

- TABULATION II -

The following factors are going to be considered in analysing the machine-tools as related specifically to the proposed group of work units:

1. Stock allowance or depth of cut.
2. Feeds.
3. Surface speed.
4. Tolerances.
5. Surface quality.

The following steps are going to be taken to present Tabulation II:

1. The work units are going to be associated to the different machine-tools that can perform them.
2. The machine-tool as related to the work unit will be analysed according to the above factors.

Note: No special purpose machine-tool was analysed.

- ROUND -

Lathes - engine, turret, automatic and automatic screw machine.

Grinding machines - cylindrical and centerless.

Drill Presses.

For the purpose of analysis, the work unit ROUND is going to be considered as being performed only on Lathes. When treating the so called SURFACEFINISH work unit, the Grinding machines will be considered. As far as Drill Presses are concerned, the author doesn't have enough information to carry on the analysis of the work unit ROUND.

- FLAT -

Shaper and Slotter.

Planer.

Broaching machine.

Milling machine.

Surface Grinder.

For the purpose of analysis, the work unit FLAT is going to be considered as being performed on Shapers and Slotters, Planers, Broaching machines and Milling machines. When treating the so called SURFACEFINISH work unit Surface Grinder will be considered.

- CONTOUR -

Milling machine.

Power Bandsaw.

Circular Saw.

For the purpose of analysis, the work unit PART is going to be considered as being performed on Hacksaws, Power Bandsaws and Circular Saws. The author doesn't have enough information on Lathes (with cut-off tool) or Milling machines (with slitting mill) or Abrasive bonded cut-off wheels to make the analysis with these machines or tools.

- HELICAL CONTOUR -

Lathes - engine, turret and automatic screw machine.

Drill Press - upright, gang and radial.

Milling machine -

Grinding machines - thread and centerless.

Precision Threading machines.

Boring machine -

- SURFACEFINISH -

Grinding machines - cylindrical, centerless and surface.

Honing machine.

Lapping machine and Hand Lapping.

Superfinish machine.

R O U N D

MACHINES \ FACTORS	STOCK ALLOWANCE OR DEPTH OF CUT	FEEDS	SURFACE SPEED IN FPM	TOLERANCES	SURFACE QUALITY IN MICRO-INCHES
ENGINE LATHE	0.005" to 0.375", though it can go as high as 0.75".	0.002" to 0.090", though feeds from 0.0007" to 0.103" can be found. (feeds are in "/per rev.). In large work, the feed will be often sufficient to produce chips of 1" width.	10 to 2,000 (the latter with carbide-tipped tool). Spindle rpm as high as 3,600 can be found.		Rough cut - 250 to 64 Finish cut - 32 to 64 Fine: ferrous metals - 16 to 32 non-ferrous metals with carbide cutters - 4.1 to 16. non-ferrous metals with diamond cutters - 1.1 to 8.
TURRET LATHE	HSS - 1/8" to 1" for rough cuts. Carbide - 1/8" to 5/8" for rough cuts. Much smaller depths of cut are used in finish cuts.	For rough and finish cuts from 0.010" to 0.061" per rev., though feeds from 0.002" to 0.168" per rev. can be found. HSS for finish cuts - 0.0018" to 0.0240" per rev. Carbide for finish cuts - 0.010" to 0.022" per rev.	40 to 1,000 (the latter with carbide-tipped tool), though speeds as high as 1,380 are used to cut Al (with carbide-tipped tool).	±0.002" on diam. is considered minimum for production. A piloted cut can be held to within ±0.001" on diam. Concentricity usually can be held to ±0.003", though with rollers and special handling on chucking ±0.002" or even less can be expected.	About 60, though better surface quality can be expected with piloted cuts.
AUTOMATIC LATHE		0.007" to 0.125" per rev., though feeds from 0.00048" to 0.289" per rev. can be found.	Somewhat slower than the other Lathes.	±0.001" on diam., though with special attachments, as low as ±0.0002" can be obtained.	Rough cut - 400 or more. Finish cut - 75 to 100. For light finish on work such as bronze bushings, surface quality around 30 can be obtained.
AUTOMATIC SCREW MACHINE	0.005" to 3/16".	As low as 0.0002" per rev. (with form tools) up to 0.008" per rev. (with single point tools)	With brass and mild or soft steel (0.10% to 0.20% carbon) and: HSS tool - from 30 (tap and chaser dies) to 150 (form tools and single point tools). Carbon steel tool - from 25 (tap and chaser dies) to 80 (form and single point tools).	±0.003" on critical diam. and ±0.010" on non-critical ones, though ±0.001" can often be held. In no case can tolerances under ±0.0005" be held. Concentricity usually can be held from ±0.002" to ±0.003".	About 60, though at increasing cost in production, better surface quality can be obtained.

F L A T

MACHINES	STOCK ALLOWANCE OR DEPTH OF CUT	FEEDS	SURFACE SPEED IN FPM	TOLERANCES	SURFACE QUALITY IN MICRO-INCHES
SHAPER AND SLOTTER	Rough cuts - ¼" to 3/8" for large work and as low as 1/8" for small work. Semi-finish cuts - 0.010" to 0.012". Finish cuts - 0.001" to 0.003".	Shaper - up to 0.100" per stroke. Slotter - up to 0.140" per stroke.	Shaper - up to 140. Slotter - up to 80.	Flatness can be held from ±0.001" to ±0.002".	Commercial - 16.1 to 32. Fine - 4.1 to 16.
PLANER	In general cuts from 1/8" for small work up to 1" for large work. For finish cuts it is possible to go as low as in Shapers or Slotters.	0.010" to 1,000" per stroke.	In general up to 240, though speeds as high as 315 can be used with carbide-tipped tools.	Flatness ±0.005", though on cast iron tolerances can be held from ±0.001" to ±0.002".	Commercial - 16.1 to 32. Fine - 4.1 to 16.
BROACHING MACHINE	Usually limited to a maximum of ½" per stroke. Up to 20 cu.in. per min. of steel can be removed. Up to 30 cu.in. per min. of cast iron can be removed.	Rise per tooth - 0.001" to 0.006".	Steel castings and forgings are normally cut at 20 to 30; brass and Al are often cut at 40.	Flatness ±0.00025".	Commercial - 16.1 to 32. Fine - 4.1 to 16.
MILLING MACHINE	Up to 0.500". With HSS mills and std. machines, not more than 25 cu.in. of cast iron or 12.5 cu.in. of steel should be removed per minute. With carbide-tipped mills it is possible to remove 150 cu.in of cast iron, 75 cu.in. of steel and in Al or Mg alloys as high as 500 cu.in. per minute.	Per tooth - from 0.002" to 0.030" sfpm.	Peripheral cutter speed: HSS tool - 30 to 2,800. Carbide-tipped tool - 150 to 10,000 (the latter used to cut Al and Mg alloys). For low-carbon and stainless steels and wrought iron, speeds in excess of 1,000 and probably 500 for high carbon and alloy steels would not be recommended.	Flatness ±0.0005".	HSS tool - 50 to 250 Carbide-tipped tool - 20 to 40 Commercial - 32 to 63. Fine - 16 to 32.

C O N T O U R

FACTORS / MACHINES	STOCK ALLOWANCE OR DEPTH OF CUT	FEEDS	SURFACE SPEED IN FPM	TOLERANCES	SURFACE QUALITY IN MICRO-INCHES
MILLING MACHINE	Up to 0.500". With HSS mills and std. machines, not more than 25 cu.in. of cast iron or 12.5 cu.in. of steel should be removed per minute. With carbide-tipped mills it is possible to remove 150 cu.in. of cast iron, 75 cu.in. of steel and in Al or Mg alloys as high as 500 cu.in. per minute.	Per tooth - 0.002" to 0.030" sfpm.	Peripheral cutter speed: HSS tool - 30 to 2,800 Carbide-tipped tool - 150 to 10,000 (the latter used to cut Al and Mg alloys). For low-carbon and stainless steels and wrought iron, speeds in excess of 1,000 and probably 500 for high carbon and alloy steels would not be recommended.	With HSS tool ±0.005" and with carbide-tipped tool ±0.0005" on cutting slots. Straightness within ±0.002" in 10 ft. has been obtained.	HSS tool - 50 to 250 Carbide-tipped tool - 20 to 40. Commercial milling obtain surface quality from 32 to 63. whereas in Fine milling surface quality from 16 to 32 has been obtained.
SHAPER AND SLOTTER	Rough cuts - ¼" to 3/8" for large work and as low as 1/8" for small work. Semi-finish cuts - 0.010" to 0.012". Finish cuts - 0.001" to 0.003".	Shaper - up to 0.100" per stroke. Slotter - up to 0.140" per stroke.	Shaper - up to 140. Slotter - up to 80.	±0.0001" to ±0.0005" can be held on small and medium dimensions. In larger parts ±0.001" to ±0.002" can be held. Depth and width on producing small slots can be held within ±0.0001".	Commercial - 16.1 to 32. Fine - 4.1 to 16.
PLANER	In general cuts from 1/8" for small work up to 1" for large work. For finish cuts it is possible to go as low as in Shapers or Slotters.	0.010" to 1,000" per stroke.	In general up to 240, though speeds as high as 315 are used with carbide-tipped tools.	±0.005" for depth and width, though in cast iron tolerances from ±0.001" to ±0.002" can be held.	Commercial - 16.1 to 32. Fine - 4.1 to 16.
BROACHING MACHINE	Usually limited to a maximum of ½" per stroke. Up to 20 cu.in. per min. of steel can be removed. Up to 30 cu.in. per min. of cast iron can be removed.	Rise per tooth: 0.004" to 0.006" for splines broaches. 0.001" to 0.006" for key way broaches. As high as 0.015" for trimming broaches. Up to 0.00275" for slotting broaches.	Steel castings and forgings are normally cut at 20 to 30; brass and Al are often cut at 40; however speeds as high as 59 have been obtained.	Splined holes can be held from ±0.001" to ±0.002" on major and minor diam. with width of splines within ±0.001". Slots can be held to ±0.0002", though ±0.001" to ±0.002" are much more economical. Spacing of lugs can be held to ±0.0003". External gears and racks, one tooth at a time being cut, can be held to ±0.0005" on tooth spacing and contour characteristics.	Commercial - 16 to 32. Fine - 4.1 to 16.

O P E N H O L E

MACHINES	SIZE OF HOLE	FEEDS	SURFACE SPEED IN FPM	TOLERANCES	SURFACE QUALITY IN MICRO-INCHES
DRILL PRESS	Up to 4" with Radial Drill Press.	Carbon steel drill - 0.0015" (1/16" drill) to 0.015" (2" drill) per rev. HSS drill - 0.0015" (1/16" drill) to 0.024" (2 7/8" drill) per rev. In Upright Drill Press it is possible to obtain feeds from 0.004" to 0.040" per rev. and in Radial Drill Press, from 0.002" to 0.125" per rev. For deep holes, using carbon steel drill or HSS drill the feeds vary from 0.0005" per rev. for small diam. drills to 0.002" for large diam. drills.	Carbon steel drill (1/16" to 2" drills) - 25 (stainless and molybdenum steel and monel metal) to 100 (brass). HSS drill (1/16" to 2" drills) - 50 (stainless and molybdenum steel and monel metal), 200 (brass) and 300 (Al). For deep hole: HSS drill - 60 to 100. Carbide drills - up to 350.	Twist drills - holes from 0.002" to 0.003" oversize on small size holes, to as much as 0.010" oversize on holes 1" in diam. Hole straightness in depth over 4 times the diam. may not be satisfactory. Carbide gun drills - diam. tolerances within ±0.0005" can often be obtained.	Twist drills - 63 to 250 normally, though as low as 32 can be obtained. Carbide gun drills - 4 to 6 on Al alloys and 7 to 8 on cast iron.
TURRET LATHE	In general up to 1".	HSS drill: For holes under 1½" - 0.005" to 0.0122" per rev. For holes over 1½" - 0.005" to 0.0163" per rev. Carbide drill - 0.010" to 0.022" per rev.	HSS drill: For holes under 1½" - 39 to 61. For holes over 1½" - 39 to 91. Carbide drill - 128 to 450.	Under average conditions, holes opened preferably not over about 4 times the diam. of the hole in depth, can be held from 0.002" to 0.010" oversize on diam. depending on size of drill. All minus tolerances can be specified as -0.001" due the fact that drills invariably cut oversize.	Twist drill - 63 to 250 normally, though as low as 32 can be obtained.

H O L E N L A R G E

FACTORS / MACHINES	STOCK ALLOWANCE OR DEPTH OF CUT	FEEDS	SURFACE SPEED IN FPM	TOLERANCES	SURFACE QUALITY IN MICRO-INCHES
BORING MACHINE	Material removed in production: rough - 0.100" to 0.225" semi-finish - 0.050" to 0.100" finish - 0.020" to 0.040" precision - 0.005" to 0.020" Depth of cut: 0.002" for bronze, up to 0.015" for Al, cast iron and steel.	Precision production: 0.001" (for Al) to 0.007" (for steel) per rev., though feeds from 0.0001" per rev. can be obtained. Larger Boring Machines: 0.010" to 0.050" per rev. Recommended feeds in "/per rev.: Diam.1" to 3" - 0.006" to 0.017" 3" to 8" - 0.017" to 0.036" 8" to 12"- 0.036" to 0.050"	Precision production: About 450 on cast iron up to about 1,500 on Al and Mg alloys are regularly used, though extremely high speeds up to 8,000 are often used with the latter mentioned alloys. Larger Boring Machines: HSS for steel - 30 to 40. HSS for cast iron - 35 to 45. Carbide - up to 500.	±0.0002" on diam. can be held on precision production. Large bores ranging up to 15" in diam. can be held to ±0.001" on diam. and cone. Hole location and depth can be held to ±0.0005", and on precision production with Jig Bores they can be held to ±0.0001". Blind holes depths can be held to ±0.0005", though ±0.001" to ±0.005" is more practical and economical.	Commercial (boring bar) - 16.1 to 32. Fine: ferrous metals - 8.1 to 16. non-ferrous metals: with carbide-tipped tool - 4.1 to 8. with diamond-tipped tool - 0.5 to 4.
TURRET LATHES (single point tool)	In Turret Lathes the amount varies in general from 1/8" to 5/8". Bores up to 15½" in diam. and 49" long can be machined with one rough and one finish cut.	HSS - 0.0018" to 0.0241" per rev., though feeds as large as 0.060" are often used. Carbide - 0.010" to 0.022" per rev.		Production tolerances of ±0.002" on diam. can be maintained.	
LATHES AND DRILL PRESSES (with Reamers)	0.010" for ½" diam. hole. 0.015" for ½" diam. hole, graduating on up to about 0.025" for 1½" holes. Insufficiently stock may result in burnishing, rather than cutting, which is undesirable.	Higher feeds than drills of corresponding diam.; 200% to 300% of those used for opening holes with drills on the same material. The more stock to be removed the lower should be the feeds. Too course feeds tend to produce spiral marks or wavy finish; too fine feeds let the reamer idle in the cut and cause excessive wear.	Slower speeds than drills of corresponding diam.; 60% to 70% of those used for opening holes with drills on the same material. The speeds run from 30 used for cutting tool steel, nickel steel, nickel cromium, etc., 70 for free cutting steel, up to about 250 for Al and its alloys.	Ordinarily holes under ½" can be held to 0.001" **total** tolerance on diam.; those from ½" to 1" can be held to 0.0015" total, and over 1" to about 0.002" total. As far as roundness is concerned, 2" holes after being finished by reamers often are out-of-round as much as ±0.002" to ±0.003".	Commercial - 16.1 to 32. Fine - 4.1 to 16.
BROACHING MACHINE	Starting hole size 1/32" smaller than the finished holes for small diam., increasing to as much as 1/16" smaller on large diam. To assure cleanup and good finish, the allowance on diam. should never be less than 1/64".	Rise per tooth: In free-machining steel it is usually from 0.0015" to 0.003".	Steel castings and forgings are normally cut at 20 to 30; brass and Al are often cut at 40.	Can be held to within ±0.001" on diam. in production.	Commercial - 16.1 to 32. Fine - 4.1 to 16.

	PART	
FACTORS / MACHINES	SPEEDS	WORK THICKNESS CAPACITY
HACKSAW	50 to 150 strokes per minute.	The width of the cut varies from 0.055" to 0.085" with regular blades, and up to 0.120" with extra-heavy blades. Slots as narrow as 0.055" in 6" bar stock can be held accurately.
POWER BANDSAW	50 to 1,500 sfpm, though for non-ferrous metals there are machines that go much higher (15,000 sfpm).	Up to 30".
CIRCULAR SAW	25 to 4,000 sfpm.	Up to 15".

FACTORS / MACHINES	HELICAL CONTOUR — TOLERANCES
ENGINE LATHE	
TURRET LATHE	Pitch and lead accuracy of threads can usually be held to that required by a class 3 fit. If more accurate threads are necessary, lead-on attachments can be utilized to attain them.
AUTOMATIC SCREW MACHINE	Fractional threads lengths unless otherwise specified are held to 1 thread. Unless the somewhat increased cost of producing and holding class 3 limits or even the greatly increased cost for class 4 limits are warranted, class 2 general practice fits are recommended for all commercial screws threads.
DRILL PRESS	Can be held to a class 3 fit on large parts.
JIG BORERS	Can be held to a class 4 fit.
MILLING MACHINE	0.001" in dimensional limits and parallelism have been readily produced. Even threads to 0.0005" in diam. (aircraft propeller threads) and 0.00025" (ordnance threads) have been on occasion obtained. An accumulated error (lead) per foot within ±0.002" has been obtained.
THREAD GRINDER	
CENTERLESS GRINDER	Threads can be produced with lead error of less than 0.0005" per inch. Pitch diam. of center-ground threads can be held from ±0.0002" to ±0.001". Roundness can be held to within ±0.0005", while concentricity of the thread form with the OD is well within ±0.003" on the largest sizes.

	HELICAL CONTOUR
FACTORS / MACHINES	TOLERANCES
PRECISION THREADING MACHINE	Lead variation, when necessary, can be held to a total of 0.0005" in 5 inches on std. thread forms which are generally considered more practical. These machines assure accuracy on the all-important dimensions and are designed for quantity production where class 3,4 and 5 gauge fits are required.

Note: Reference was made only for thread making. The cutting of helical flutes was not analyzed here.

FACTOR / MACHINE		SURFACE QUALITY IN MICRO-INCHES
	ness and hin ength as 1" on diam usually is	Commercial (hardened and unhardened pieces) - 16.1 to 32. Fine first class - 4.1 to 8. Fine second class - 8.1 to 16. Superfine for master and ordinary gages - 1.1 to 4. Superfine for slip gages - 0.5 to 2. of 5 and
	finished eld to flat- 5", paral- 005", and 01" to e size and bands can s.	

S U R F A C E F I N I S H

FACTORS / MACHINES	STOCK ALLOWANCE OR DEPTH OF CUT	SURFACE SPEED IN FPM	TOLERANCES	SURFACE QUALITY IN MICRO-INCHES
LAPPING MACHINE	Rough (hand) - 0.0005". Fine (hand) - 0.0001". In production stock removal never exceeds 0.0005".		Centerless Lappers - total variation of 0.00005" on diam. and 0.000025" on straightness. With loose abrasive method dimensional accuracy within ±0.000005" is said to be possible. Surfaces flat to within one light band (11.6 millionths) can be produced on Vertical Lappers. Parallel flats can be held to within ±0.0001" to ±0.00005" on parallelism. Long rods can be finished to within ±0.0001" to ±0.0002" for roundness and taper.	In hand lapping surface quality of 1 or even less can be attained. In production surface quality of 2 or 3 is preferable, due time and cost.
SUPERFINISH MACHINE	0.0001" to 0.0003", though actual change through removal of high spots seldom exceeds 0.0001" in most production work.	Work speed - 10 to 60, though it is usually between 50 and 60. Abrasive speed - up to 80, with an average of 55.		Normally a surface quality ranging from 2 to 3 is obtained in one minute or even less. Where design demands, surfaces of less than 1 can be produced.

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Data and information from the following machine-tool Manufacturers:

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The Warner & Swasey Co., Cleveland, Ohio - Turret and Automatic Lathes.

Jones & Lamson Machine Co., Springfield, Vermont - Automatic Lathes.

LeBlond Machine Tool Co., Cincinnati, Ohio - Engine Lathes.

The Monarch Machine Tool Co., Sidney, Ohio - Engine Lathes.

Cone Automatic Machine Tool Co., Windsor, Vermont - Automatic Lathes.

The Cleveland Automatic Machine Co., Cincinnati, Ohio - Automatic Lathes and Boring Machines.

Brown & Sharp Mfg. Co., Providence, Rhode Island - Automatic Lathes, Cylindrical and Surface Grinders.

Cincinnati Milling and Grinding Machine, Inc., Cincinnati, Ohio - Milling Machines Cylindrical and Centerless Grinders and Broaching Machines.

Kearney & Trecker Corporation, Milwaukee, Wisconsin - Milling Machines.

The Cincinnati Bickford Tool Co., Oakley, Cincinnati, Ohio Drill Presses.

The Carlton Machine Tool Co., Cincinnati, Ohio - Drill Presses.

Gidding & Lewis, Fond Du Lac, Wisconsin - Planers, Shapers and Boring Machines.

The G. A. Gray Co., Cincinnati, Ohic - Planers and Boring Machines.

The Rockford Machine Tool Co., Rockford, Ill. - Planers, Shapers and Slotters.

Landis Tool Co., Waynesboro, Pa. - Cylindrical and Centerless Grinders.

Norton Co., Worcester, Massachusetts - Cylindrical and Surface Grinders.

American Broaching & Machine Co., Ann Arbor, Michigan - Broaching Machines.

The Heald Machine Co., Worcester, Massachusetts - Boring Machines.

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